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Abstract

Recent events in financial markets have underlined the importance of analyzing the link between the financial health of banks and real economic activity. This paper contributes to this analysis by constructing a dynamic general equilibrium model in which the balance sheet of banks affects the propagation of shocks. We use the model to conduct quantitative experiments on the economy's response to technology and monetary policy shocks, as well as to disturbances originating within the banking sector, which we interpret as episodes of distress in financial markets. We show that, following adverse shocks, economies whose banking sectors remain well-capitalized experience smaller reductions in bank lending and less pronounced downturns. Bank capital thus increases an economy's ability to absorb shocks and, in doing so, affects the conduct of monetary policy. The model is also used to shed light on the ongoing debate over bank capital regulation.

JEL classification: E44, E52, G21
Bank classification: Transmission of monetary policy; Financial institutions; Financial system regulation and policies; Economic models

Résumé

Les récents événements survenus sur les marchés financiers illustrent à quel point il est important d'analyser la relation entre la santé financière des banques et l'activité économique réelle. Les auteurs construisent pour ce faire un modèle dynamique d'équilibre général dans lequel le bilan des banques influe sur la propagation des chocs. À l'aide de ce modèle, ils mènent des simulations quantitatives concernant la réaction de l'économie à un choc technologique, à un choc de politique monétaire ainsi qu'à des perturbations émanant du secteur bancaire, qu'ils assimilent à des périodes de détresse sur les marchés financiers. Les auteurs montrent que, lors de chocs défavorables, les économies dont le secteur bancaire demeure bien doté en capital ne voient pas le crédit bancaire diminuer autant et connaissent un ralentissement moins marqué. La présence de banques au bilan solide aide donc l'économie à mieux absorber les chocs, ce qui a des répercussions sur la conduite de la politique monétaire. Le modèle utilisé apporte un éclairage intéressant au débat en cours sur la réglementation des fonds propres des banques.

Classification JEL : E44, E52, G21
Classification de la Banque : Transmission de la politique monétaire; Institutions financières; Réglementation et politiques relatives au système financier; Modèles économiques

1 Introduction

The balance sheets of banks worldwide have recently come under stress, as significant asset writedowns led to sizeable reductions in bank capital. In turn, these events appear to have generated a 'credit crunch', in which banks cut back on lending and firms found it harder to obtain external financing. Concerns have been raised that economic activity will be undermined by these adverse financial conditions, much like shortages in bank capital contributed to the slow recovery from the 1990-91 recession (Bernanke and Lown, 1991).[1] This has sustained interest for a quantitative business cycle model that can analyze the interactions between bank capital, bank lending, economic activity and monetary policy.

This paper undertakes this analysis and develops a New Keynesian model in which the relationship between the balance sheet of banks and macroeconomic performance matters. We show that the net worth of banks (their capital) increases an economy's ability to absorb shocks. In the model, banks (or banking sectors) that have low capital during periods of negative technology growth reduce lending significantly, producing sharp downturns in economic activity. By contrast, economies whose banks remain well-capitalized during these periods experience smaller decreases in bank lending and economic activity. These different responses influence monetary policy, as the more moderate downturns associated with well-capitalized banks require less aggressive reactions from monetary authorities. Additionally, we consider shocks that originate within the banking sector and produce sudden shortages in bank capital. These shocks lead to reductions in bank lending, aggregate investment, and economic activity. Overall, our model suggests that the balance sheet of banks importantly affects the propagation of shocks and how policy makers should respond to them. Further, it can be used to shed light on recent debates about the regulation of bank capital.

The model we formulate includes several nominal and real rigidities, in the spirit of Christiano et al. (2005). We depart from much of this literature, however, by accounting for the role of bank capital in the transmission of shocks. In the model, investors provide the bulk of loanable funds but do not monitor firms receiving loans: this activity is fulfilled by banks. However, banks may lack the incentive to do so adequately, because monitoring is privately costly and any resulting increase in the risk of loan portfolios is mostly borne by investors. This moral hazard problem is mitigated when banks are well-capitalized and have a lot to loose from loan default. As a result, higher bank capital increases the

[1] Additional evidence suggests that decreases in the capitalization of Japanese banks in the late 1980s had adverse effects on their lending and on economic activity in areas in the U.S. where these banks had a major presence (Peek and Rosengren, 1997, 2000). Moreover, bank-level data (Kishan and Opiela, 2000, 2006; Van den Heuvel, 2007) shows that poorly capitalized banks reduce lending more significantly following monetary policy contractions. Finally, Van den Heuvel (2002) reports that the GDP of states whose banking systems are poorly capitalized are more sensitive to monetary policy shocks.

ability to raise loanable funds and facilitates bank lending. Over the business cycle, this mechanism implies that the dynamics of bank capital affect the propagation of shocks.

A second source of moral hazard is present in the model and affects the relationship between banks and firms (entrepreneurs). As a result, entrepreneurial net worth also affects the economy's dynamics. This double moral hazard framework thus allows for a rich set of interactions between bank capital, entrepreneurial net worth, economic activity, and monetary policy.[2]

Bank capital affects propagation as follows. A negative technology shock, for example, reduces the value of investment goods produced by entrepreneurs, making lending to them less profitable. Banks thus find it harder to attract loanable funds from investors. To compensate, market discipline imposes that they finance a larger share of entrepreneur projects from their own net worth. This requires an increase in their capital-to-loans (or capital adequacy) ratio. Since bank net worth is comprised of retained earnings, it cannot adjust much and therefore bank lending decreases significantly, as does aggregate investment. This sets the stage for second-round effects in subsequent periods, in which lower investment leads to lower bank earnings and net worth, decreasing further banks' ability to attract loanable funds and provide external financing in support of economic activity.[3]

Our results show that in this framework, economies whose banks remain well-capitalized when affected by negative shocks experience less severe downturns. This arises because in these economies, the ability of banks to provide funding does not diminish as much following adverse shocks, which moderates the responses in aggregate investment and output. In addition, inflationary pressures resulting from the shocks are subdued in these economies, reducing the required reaction from monetary authorities. By contrast, the same adverse shock leads to more dramatic fluctuations when it affects economies with poorly-capitalized banking sectors.

In our model, bank capital adequacy ratios arise from market discipline. Model simulations with technology and monetary policy shocks show these ratios covary negatively with the cycle, imposing tighter banking norms when output growth is weak and looser ones when it is strong. This countercyclical pattern matches the one present in the data, which constitutes an important test of the validity of our framework. Although tightening banking norms in recessions may exacerbate the business cycle, in this case it represents the optimal response to adverse shocks affecting the overall economy.

The model also predicts that sudden and occasional shortages in bank capital have a negative impact on the economy. We show this by studying shocks that originate within the

[2]The double moral hazard framework we employ is introduced in a static setting by Holmstrom and Tirole (1997) and used by Chen (2001) in a simple model without nominal rigidities and monetary policy.

[3]The influence of entrepreneurial net worth reinforces this mechanism, in a manner similar to that highlighted by the 'financial accelerator' literature (Carlstrom and Fuerst, 1997; Bernanke et al., 1999).

banking sector and cause sudden drops in bank capital. These shocks are meant to capture periods of weakness in financial markets and they lead to lower bank lending, investment, and output. Interestingly, capital adequacy ratios are procyclical following these episodes: as the sudden scarcity of bank capital undermines bank lending and economic activity, financial markets now seek to conserve bank capital and, as a result, capital adequacy ratios loosen just as output weakens. Put differently, our results suggests that whether capital adequacy ratios ought to be procyclical or not depends on the nature of shocks.

Previous work on the role of bank capital in the transmission of shocks includes Van den Heuvel (2008), whose bank capital dynamics are linked to explicit regulatory requirements; Meh and Moran (2004), in which limited participation rather than price rigidity generates monetary non-neutralities; and Aikman and Paustian (2006) and Markovic (2006), whose framework features costly state verification. This views banks as reorganizers of troubled firms, rather than agents able to prevent entrepreneurs from undertaking inferior projects, their core function in our framework. Finally, Christiano et al. (2007) and Goodfriend and McCallum (2007) analyze quantitatively the interaction between banking and macroeconomic shocks but do not emphasize bank capital.

The remainder of this paper is organized as follows. Sections 2 and 3 present the model and its calibration. Section 4 describes the propagation mechanism by which bank and entrepreneurial net worth affect the transmission of shocks. It also shows that a key component of this mechanism, the counter-cyclical movement in bank capital adequacy ratios, is also present in the data. Section 5 presents our main findings. It shows that economies with well-capitalized banks can absorb negative shocks better, and that this capacity may be affected by financial sector weaknesses. Section 6 concludes.

2 The Model

2.1 The environment

This section describes the structure of the model and the optimization problems facing the economy's agents. Time is discrete, and one model period represents a quarter. There are five types of economic agents: households, entrepreneurs, banks, firms producing final goods and firms producing intermediate goods. In addition, a monetary authority sets interest rates according to a Taylor-type rule.

There are two sectors in the economy. The first one produces the economy's final good and its structure is similar to that in Christiano et al. (2005): competitive firms assemble final goods using intermediate goods produced by a set of monopolistically competitive firms facing price rigidities.

The second sector produces capital goods. These goods are produced by entrepreneurs, who have access to a stochastic process that transforms final goods into capital. Two moral hazard problems are present in this sector. First, entrepreneurs can affect their technology's probability of success, by undertaking projects with low probability of success but private benefits. Monitoring entrepreneurs helps reduce this problem, but does not eliminate it. To give entrepreneurs the incentive not to undertake these projects, they are required to invest their own net worth when obtaining financing. All things equal, higher entrepreneurial net worth thus increases access to financing and facilitates capital goods production.

Banks alone possess the technology to monitor entrepreneurs. As a result, households invest funds at banks and delegate to them the task of financing and monitoring entrepreneurs. However, bank monitoring is privately costly and without proper incentives, banks may not provide the correct level of monitoring. To give them the incentive to do so, households seek to invest funds at high net worth (well-capitalized) banks. Well-capitalized banks thus attract more loanable funds and have stronger lending capacity; by contrast, poorly capitalized banks find it difficult to attract loanable funds and lend less. A key contribution of our analysis is to investigate quantitatively this link between bank net worth and bank lending. Figure 1 illustrates the sequence of events that unfold in each period.

2.2 Final good production

Final Good Assembly

Competitive firms produce the final good by combining a continuum of intermediate goods indexed by $j \in (0,1)$ using the standard Dixit-Stiglitz aggregator:

$$Y_t = \left(\int_0^1 y_{jt}^{\frac{\xi_p - 1}{\xi_p}} \mathrm{d}j \right)^{\frac{\xi_p}{\xi_p - 1}}, \qquad \xi_p > 1, \tag{1}$$

where y_{jt} denotes the time t input of the intermediate good j, and ξ_p is the constant elasticity of substitution between intermediate goods.

Profit maximization leads to the following first-order condition for the choice of y_{jt}:

$$y_{jt} = \left(\frac{p_{jt}}{P_t} \right)^{-\xi_p} Y_t, \tag{2}$$

which expresses the demand for good j as a function of its relative price p_{jt}/P_t and of overall production Y_t. Imposing the zero-profit condition leads to the usual definition of the final good price index P_t:

$$P_t = \left(\int_0^1 {p_{jt}}^{1-\xi_p} \mathrm{d}j \right)^{\frac{1}{1-\xi_p}}. \tag{3}$$

Intermediate Goods

Firms producing intermediate goods operate under monopolistic competition and nominal rigidities in price setting. The firm producing good j operates the technology

$$y_{jt} = \begin{cases} z_t k_{jt}^{\theta_k} h_{jt}^{\theta_h} {h_{jt}^e}^{\theta_e} {h_{jt}^b}^{\theta_b} - \Theta & , \quad z_t k_{jt}^{\theta_k} h_{jt}^{\theta_h} {h_{jt}^e}^{\theta_e} {h_{jt}^b}^{\theta_b} \geq \Theta \\ 0 & , \quad \text{otherwise} \end{cases} \tag{4}$$

where k_{jt} is the amount of capital services used by firm j and h_{jt} is household labour employed by the firm. In addition, h_{jt}^e and h_{jt}^b represent labour services from entrepreneurs and bankers.[4] Fixed costs of production are represented by the parameter Θ, while z_t is an aggregate technology shock that follows the autoregressive process

$$\log z_t = \rho_z \log z_{t-1} + \varepsilon_{zt}, \tag{5}$$

where $\rho_z \in (-1, 1)$, and ε_{zt} is *i.i.d.* with mean 0 and standard deviation σ_z.

Minimizing production costs for a given demand solves the problem

$$\min_{\{k_{jt}, h_{jt}, h_{jt}^e, h_{jt}^b\}} r_t k_{jt} + w_t h_{jt} + w_t^e h_{jt}^e + w_t^b h_{jt}^b \tag{6}$$

$$s.t. \;\; y_{jt} = z_t k_{jt}^{\theta_k} h_{jt}^{\theta_h} {h_{jt}^e}^{\theta_e} {h_{jt}^b}^{\theta_b} - \Theta, \tag{7}$$

where the multiplier associated with (7) is s_t and represents marginal cost. The (real) rental rate of capital services is r_t, while w_t represents the real household wage. w_t^e and w_t^b are the compensation given entrepreneurs and banks, respectively, for their labour. Developing the usual first-order conditions and evaluating the objective function at the optimum shows that total production costs, net of fixed costs, are equal to $s_t y_{jt}$.

The price-setting environment is as follows. Assume that each period, firm j receives, with probability $1 - \phi_p$, the signal to reoptimize and choose a new price, whereas with probability ϕ_p, the firm does not reoptimize and simply indexes its price to last period's aggregate inflation. For a non-reoptimizing firm, we thus have

$$p_{jt} = (1 + \pi_{t-1}) p_{j,t-1},$$

where $1 + \pi_t \equiv P_t / P_{t-1}$ is aggregate price inflation. A reoptimizing firm chooses $\widetilde{p_{jt}}$ in order to maximize expected profits until the next price signal is received. Note that after k periods with no reoptimizing, the firm's price will be

$$p_{jt+k} = \prod_{s=0}^{k-1} (1 + \pi_{t+s}) \, \widetilde{p_{jt}}. \tag{8}$$

[4]Following Carlstrom and Fuerst (1997, 2001), we include labour services from entrepreneurs and bankers in the production function so that these agents always have non-zero wealth to pledge in the financial contracts described below. The calibration sets the value of θ_e and θ_b so that the influence of these labor services on the model's dynamics is negligible.

The profit maximizing problem is thus

$$\max_{\widetilde{p}_{jt}} E_t \sum_{k=0}^{\infty} (\beta\phi_p)^k \lambda_{t+k} \left[\frac{p_{jt+k} y_{jt+k}}{P_{t+k}} - s_{t+k} y_{jt+k} \right], \tag{9}$$

subject to (2) and (8).[5]

2.3 Capital good production

Each entrepreneur has access to a technology producing capital goods. The technology is stochastic: an investment of i_t units of final goods returns Ri_t ($R > 1$) units of capital if the project succeeds, and zero units if it fails. The project scale i_t is variable and determined by the financial contract linking the entrepreneur and the bank (discussed below). Returns from entrepreneurial projects are publicly observable.

Different projects are available to the entrepreneurs: although they all produce the same public return R when successful, they differ in their probability of success. Without proper incentive, entrepreneurs may deliberately choose a project with low success probability, because of private benefits associated with that project. Following Holmstrom and Tirole (1997) and Chen (2001), we formalize this moral hazard problem by assuming that entrepreneurs can privately choose between three different projects.

First, the "good" project corresponds to a situation where the entrepreneur "behaves." This project has a high probability of success, denoted α^g, and zero private benefits. The second project corresponds to a "shirking" entrepreneur: it has a lower probability of success $\alpha^b < \alpha^g$, and provides the entrepreneur with private benefits proportional to the project size ($b\, i_t,\ b > 0$). Finally, a third project corresponds to a higher level of shirking: although it has the same low probability of success α^b, it provides the entrepreneur with more private benefits $B\, i_t$, $B > b$.[6]

Banks have access to an imperfect monitoring technology, which can detect the shirking project with high private benefits B but not the one with low private benefits b.[7] Even monitored entrepreneurs may therefore choose to undertake the first shirking project, instead of behaving and running the "good" project. Ensuring that they have an incentive to do the latter is a key component of the financial contract discussed below.

Bank monitoring is privately costly: to prevent entrepreneurs from undertaking the B project, a bank must pay a non-verifiable cost μi_t in final goods. This creates a second

[5] Time-t profits are discounted by λ_t, the marginal utility of household income.

[6] The existence of two shirking projects allows the model to analyze imperfect bank monitoring.

[7] Bank monitoring consists of activities that prevent managers from investing in inferior projects: inspection of cash flows and balance sheets, verification that firms conform with loan covenants, etc. This interpretation follows Holmstrom and Tirole (1997). By contrast, bank monitoring in the costly state verification literature is associated with reorganizing the activities of troubled companies.

moral hazard problem, affecting the relationship between banks and their investors. A bank that pledges its own net worth reduces moral hazard because it has an incentive to adequately monitor the entrepreneurs it finances. Investors thus seek to invest funds at high net worth (well-capitalized) banks, who therefore have better access to loanable funds and lend more. Finally, the returns in the projects funded by each bank are assumed to be perfectly correlated. Correlated projects can arise because banks specialize (across sectors, regions or debt instruments) to become efficient monitors. The assumption of perfect correlation improves the model's tractability and could be relaxed at the cost of additional computational requirements.[8]

2.4 Financing entrepreneurs : the financial contract

An entrepreneur with net worth n_t wishing to undertake a project of size $i_t > n_t$ needs external financing $i_t - n_t$. The bank provides this financing by combining funds from investors (households) and its own net worth. Denote by d_t the real value of the funds from investors and by a_t the net worth of this bank. The bank's lending capacity, net of the monitoring costs, is thus $a_t + d_t - \mu i_t$.

The (optimal) financial contract has the following structure. Assume the presence of inter-period anonymity, which restricts the analysis to one-period contracts.[9] Further, we concentrate on equilibria where all entrepreneurs choose to pursue the good project, so that α^g represents the project's probability of success. The contract determines an investment size i_t, contributions to the financing from the bank (a_t) and the bank's investors (d_t), and how the project's return is shared among the entrepreneur ($R_t^e > 0$), the bank ($R_t^b > 0$) and the investors ($R_t^h > 0$). Limited liability ensures that no agent earns a negative return.

Formally, the contract seeks to maximize the expected return to the entrepreneur, subject to incentive, participation, and feasibility constraints, as follows:

$$\max_{\{i_t,a_t,d_t,R_t^e,R_t^b,R_t^h\}} \quad q_t\alpha^g R_t^e i_t, \quad \text{s.t.} \tag{10}$$

$$q_t\alpha^g R_t^e i_t \geq q_t\alpha^b R_t^e i_t + q_t b i_t; \tag{11}$$

$$q_t\alpha^g R_t^b i_t - \mu i_t \geq q_t\alpha^b R_t^b i_t; \tag{12}$$

$$q_t\alpha^g R_t^b i_t \geq (1+r_t^a)a_t; \tag{13}$$

$$q_t\alpha^g R_t^h i_t \geq (1+r_t^d)d_t; \tag{14}$$

$$a_t + d_t - \mu i_t \geq i_t - n_t; \tag{15}$$

$$R_t^e + R_t^b + R_t^h = R. \tag{16}$$

[8] Bank capital retains a role in the transmission of shocks so long as banks cannot completely diversify the risk in their lending portfolio. If this were the case, a bank's incentive to monitor would not depend on its capital (Diamond, 1984; Williamson, 1987).

[9] This follows Carlstrom and Fuerst (1997) and Bernanke et al. (1999).

Condition (11) ensures that entrepreneurs have the incentive to choose the good project: it states that their expected return is at least as high as the one they would get (inclusive of private benefits) if the shirking project with low private benefit were undertaken.[10] Condition (12) ensures that the bank has a sufficient incentive to monitor: it states that the bank's expected return, if monitoring, is at least as high as if it did not monitor and the project's probability of success, consequently, was low. Next, (13) and (14) are the participation constraints of the bank and the investing households, respectively: they state that the funds engaged earn a return sufficient to cover their (market-determined) returns. These are r_t^a for bank net worth (bank capital) and r_t^d for household investors. Finally, (15) indicates that the bank's loanable funds must cover the entrepreneur's financing needs and (16) states that the shares of a successful project allocated to the three agents add up to total return.

In equilibrium, (11) and (12) hold with equality, so with (16) we have:

$$R_t^e = \frac{b}{\Delta\alpha}; \tag{17}$$

$$R_t^b = \frac{\mu}{q_t \Delta\alpha}; \tag{18}$$

$$R_t^h = R - \frac{b}{\Delta\alpha} - \frac{\mu}{q_t \Delta\alpha}; \tag{19}$$

where $\Delta\alpha \equiv \alpha^g - \alpha^b > 0$.

Note from (17) and (18) that the project return shares allocated to the entrepreneur and the banker are linked to the severity of the moral hazard problem associated with their decisions. In economies where the private benefit b or the monitoring cost μ is higher, the project share allocated to the entrepreneur (or the bank) needs to increase. In turn, (19) shows that the share of project return that can be promised to households investing in the bank is limited by the two moral hazard problems: if either were to worsen, the payment to households would decrease.

Introducing (19) into the participation constraint (14), which holds with equality, yields

$$(1 + r_t^d) d_t = q_t \alpha^g \left(R - \frac{b}{\Delta\alpha} - \frac{\mu}{q_t \Delta\alpha} \right) i_t; \tag{20}$$

next, using (15) to eliminate d_t and then dividing by the project size i_t, yields

$$(1 + r_t^d) \left[(1 + \mu) - \frac{a_t}{i_t} - \frac{n_t}{i_t} \right] = q_t \alpha^g \left(R - \frac{b}{\Delta\alpha} - \frac{\mu}{q_t \Delta\alpha} \right). \tag{21}$$

Finally, solving for i_t in (21) yields

$$i_t = \frac{n_t + a_t}{1 + \mu - \frac{q_t \alpha^g}{1 + r_t^d} \left(R - \frac{b}{\Delta\alpha} - \frac{\mu}{\Delta\alpha q_t} \right)} = \frac{n_t + a_t}{G_t}, \tag{22}$$

[10] In equilibrium, banks monitor so that entrepreneurs do not undertake the shirking project with high private benefits.

with

$$G_t \equiv 1 + \mu - \frac{q_t \alpha^g}{1 + r_t^d} \left(R - \frac{b}{\Delta\alpha} - \frac{\mu}{\Delta\alpha q_t} \right)$$

and $1/G_t$ is the leverage achieved by the financial contract over the combined net worth of the bank and the entrepreneur. G_t does not depend on individual characteristics and thus leverage is constant across all contracts in the economy.

Expression (22) describes how the project size an entrepreneur can undertake depends on his net worth n_t, as well as the net worth a_t that his bank pledges towards the project. Further, since $\frac{\partial G_t}{\partial q_t} < 0$ and $\frac{\partial G_t}{\partial r_t^d} > 0$, an increase in the price of investment goods allow for larger entrepreneurial projects, while an increase in the cost of loanable funds r_t^d lowers project size.

One interpretation of the financial contract described above is that it requires banks to meet solvency conditions that determine how much loanable funds they can attract. These solvency conditions manifest themselves as a market-generated capital adequacy ratio that depends on economy-wide variables like the market (required) rates of return on bank equity (r_t^a) and bank deposits r_t^d, as well as on the price of investment good price q_t. This ratio is defined as

$$\kappa_t \equiv \frac{a_t}{a_t + d_t} = \frac{\frac{\mu}{\Delta\alpha q_t}}{\frac{\mu}{\Delta\alpha q_t} + \frac{1+r_t^a}{1+r_t^d}} \left(R - \frac{b}{\Delta\alpha} - \frac{\mu}{\Delta\alpha q_t} \right). \tag{23}$$

The model simulations we explore below analyze the business cycle behaviour of this ratio.

2.5 Households

There exists a continuum of households indexed by $i \in (0, \eta^h)$. Households consume, allocate their money holdings between currency and investment in banks (deposits), supply units of specialized labour, choose a capital utilization rate, and purchase capital.

There are two sources of idiosyncratic uncertainty affecting households. First, the Calvo (1983)-type wage-setting environment described below implies that their relative wages and hours worked are different; consequently so are labor earnings. Second, some bank deposits, associated with failed projects, do not pay their expected return.

The idiosyncratic income uncertainty implies that households make different consumption, asset allocation and capital holding decisions. We abstract from this heterogeneity by referring to the results in Erceg et al. (2000) who show, in a similar environment, that the existence of state-contingent securities makes households homogenous with respect to consumption and saving decisions. We assume the existence of these securities and our notation below reflects their equilibrium effect: consumption, assets and the capital stock are not contingent on household type i, though wages and hours worked are.

Lifetime expected utility of household i is

$$E_0 \sum_{t=0}^{\infty} \beta^t u(c_t^h - \gamma c_{t-1}^h, l_{it}, M_t^c/P_t), \tag{24}$$

where c_t^h is consumption in period t, γ measures the importance of habit formation in utility, l_{it} is hours worked, and M_t^c/P_t denotes the real value of currency held.

The household begins period t with money holdings M_t and receives a lump-sum money transfer X_t from the monetary authority.These monetary assets are allocated between funds invested at a bank (deposits) D_t and currency held M_t^c so we have

$$M_t + X_t \geq D_t + M_t^c. \tag{25}$$

In making this decision, households weigh the tradeoff between the (expected) return $1+r_t^d$ when funds are invested with a bank and the utility obtained from holding currency.

Households also make a capital utilization decision. Starting with beginning-of-period capital stock k_t^h, they can produce capital services $u_t k_t^h$ with u_t the utilization rate. Total revenues from renting capital are thus $r_t u_t k_t^h$. The benefit of increased utilization must be weighted against utilization costs, expressed by $\upsilon(u_t)k_t^h$, where $\upsilon(.)$ is a convex function.[11] Finally, the household receives labour earnings $(W_{it}/P_t)\, l_{it}$, as well as dividends Π_t from firms producing intermediate goods.

Income from these sources is used to purchase consumption, new capital goods (priced at q_t), and money balances carried into the next period M_{t+1}, subject to the constraint

$$c_t^h + q_t i_t^h + \frac{M_{t+1}}{P_t} = (1 + r_t^d)\frac{D_t}{P_t} + r_t u_t k_t^h - \upsilon(u_t)k_t^h + \frac{W_{it}}{P_t} l_{it} + \Pi_t + \frac{M_t^c}{P_t}, \tag{26}$$

with the associated Lagrangian λ_t representing the marginal utility of income. The capital stock evolves according to the standard accumulation equation:

$$k_{t+1}^h = (1 - \delta)k_t^h + i_t^h. \tag{27}$$

Wage Setting

We follow Erceg et al. (2000) and Christiano et al. (2005) and assume that each household supplies a specialized labour type l_{it}, while competitive labour aggregators assemble all such types into one composite input using the technology

$$H_t \equiv \left(\int_0^1 l_{it}^{\frac{\xi_w - 1}{\xi_w}} \mathrm{d}i \right)^{\frac{\xi_w}{\xi_w - 1}}, \qquad \xi_w > 1. \tag{28}$$

[11] The utilization choice is defined by the first order condition $r(t) = \upsilon'(u_t)$, or

$$\hat{r}_t = \frac{\upsilon''(u)u}{\upsilon'(u)} \hat{u}_t,$$

up to a first-order approximation (a hatted variable denotes deviation from steady state and u is steady-state utilization). Section 3 discusses the calibration of $\upsilon(.)$.

The demand for each labour type is therefore

$$l_{it} = \left(\frac{W_{i,t}}{W_t}\right)^{-\xi_w} H_t, \tag{29}$$

where W_t is the aggregate wage (the price of one unit of composite labour input H_t). Expression (29) expresses the demand for labour type i as a function of its relative wage and economy-wide labor H_t.

Households set wages according to a variant of the Calvo mechanism used in the price-setting environment above. Each period, household i receives with probability $1 - \phi_w$ the signal to reoptimize and choose a new wage; with probability ϕ_w, reoptimizing is not allowed but the wage increases at last period's rate of price inflation, so that $W_{i,t} = (1+\pi_{t-1})W_{i,t-1}$. For more details on this wage-setting environment, see Erceg et al. (2000) and Christiano et al. (2005).

2.6 Entrepreneurs and Bankers

There exists a continuum of risk neutral entrepreneurs and bankers, whose population masses are fixed at η^e and η^b, respectively. Each period, a fraction $1 - \tau^e$ of entrepreneurs and $1 - \tau^b$ of bankers learn that they will exit the economy at the end of the period's activities. This implies that entrepreneurs and bankers discount the future more heavily than households. Those exiting are replaced by new agents with zero assets.[12]

Entrepreneurs and bankers solve similar optimization problems: in the first part of each period, they accumulate net worth, which they invest in entrepreneurial projects later in that period. Exiting agents consume accumulated wealth while surviving agents save. These agents differ, however, with regard to their technological endowments: entrepreneurs have access to a capital-good producing technology, while bankers have monitoring capacities.

A typical entrepreneur starts period t with holdings k_t^e in capital goods, which are rented to intermediate-good producers. The corresponding rental income, combined with the value of the undepreciated capital and the small wage received from intermediate-good producers, constitute the net worth n_t that an entrepreneur can invest in a capital-good production project:[13]

$$n_t = (r_t + q_t(1-\delta))\, k_t^e + w_t^e. \tag{30}$$

[12] This follows Bernanke et al. (1999). Because of financing constraints, entrepreneurs and bankers have a strong incentive to accumulate net worth until they no longer need financial markets. Assuming that they have high discount rates dampens this accumulation motive and ensures that a steady state with operative financing constraints exists.

[13] Allowing entrepreneurs and bankers to vary utilization for their capital, as households do, does not affect results.

Similarly, a typical banker starts period t with holdings of k_t^b capital goods and rents capital services to firms producing intermediate goods. Once income is received, this bank can count on net worth

$$a_t = (r_t + q_t(1-\delta))\, k_t^b + w_t^b. \tag{31}$$

Each entrepreneur then undertakes an investment project in which all available net worth n_t is invested. In addition, the entrepreneur's bank invests directly its own net worth a_t in addition to the funds d_t invested by households. As described above, an entrepreneur whose project is successful receives a payment of $R_t^e i_t$ in capital goods whereas the bank receives $R_t^b i_t$; unsuccessful projects have zero return.

At the end of the period, entrepreneurs and bankers associated with successful projects but having received the signal to exit the economy use their returns to buy and consume final (consumption) goods. Successful and surviving agents save their entire return, which becomes their beginning-of-period real assets at the start of the subsequent period, k_{t+1}^e and k_{t+1}^b. This represents an optimal choice since these agents are risk neutral and the high return on internal funds induces them to postpone consumption. Unsuccessful agents neither consume nor save.

2.7 Monetary policy

Monetary policy sets the nominal interest rate according to the following rule:

$$r_t^d = (1-\rho_r) r^d + \rho_r r_{t-1}^d + (1-\rho_r)\left[\rho_\pi(\pi_t - \overline{\pi}) + \rho_y \hat{y}_t\right] + \epsilon_t^{mp}, \tag{32}$$

where r^d is the steady-state deposit rate, $\overline{\pi}$ is the monetary authority's inflation target, and $\hat{y}_t$ represents output deviation from steady state.[14] ϵ_t^{mp} is a monetary policy shock with standard deviation σ^{mp}.

2.8 Aggregation

As a result of the linear specifications in the production function for capital goods, the private benefits accruing to entrepreneurs, and the monitoring costs facing banks, the distributions of net worth and bank capital across agents have no effects on aggregate investment I_t, which is obtained by summing up the individual investment projects described in (22):

$$I_t = \frac{N_t + A_t}{G_t}, \tag{33}$$

where N_t and A_t denote the aggregate levels of entrepreneurial net worth and bank capital. This represents the supply curve for capital goods in the economy. As was the case for the individual relation (22), notice that a fall in banking net worth A_t shifts this curve to the

[14] When discussing results, we use the header "Short Term Rate" for r_t^d.

left and, all things equal, decreases aggregate investment I_t. A decrease in entrepreneurial net worth N_t has a similar effect.

The bank capital adequacy ratio defined in (23) is also easily aggregated to yield the following economy-wide measure:

$$\kappa_t = \frac{A_t}{(1+\mu)I_t - N_t}, \tag{34}$$

while the economy-wide equivalent to the participation constraint of banks (13) serves to define the equilibrium return on bank net worth:

$$1 + r_t^a = \frac{q_t \alpha^g R_t^b I_t}{A_t}. \tag{35}$$

The population masses of entrepreneurs, banks and households are η^e, η^b and $\eta^h \equiv 1 - \eta^e - \eta^b$. As a result, the aggregate levels of capital holdings are

$$K_t^e = \eta^e k_t^e; \;\; K_t^b = \eta^b k_t^b; \;\; K_t^h = \eta^h k_t^h. \tag{36}$$

Meanwhile, the aggregate levels of entrepreneurial and banking net worth (N_t and A_t) are found by summing (30) and (31) across all agents:

$$N_t = [r_t + q_t(1-\delta)]\, K_t^e + \eta^e w_t^e; \tag{37}$$

$$A_t = [r_t + q_t(1-\delta)]\, K_t^b + \eta^b w_t^b; \tag{38}$$

As described above, successful entrepreneurs and banks that do not exit the economy (an event that occurs with probability τ^e and τ^b, respectively) save all available wealth, because of risk-neutral preferences and the high return on internal funds. Their beginning-of-period assets holdings in $t+1$ are thus

$$K_{t+1}^e = \tau^e \alpha^g R_t^e I_t; \tag{39}$$

$$K_{t+1}^b = \tau^b \alpha^g R_t^b I_t. \tag{40}$$

Combining (33) to (37)-(40) yields the following laws of motion for N_{t+1} and A_{t+1}:

$$N_{t+1} = [r_{t+1} + q_{t+1}(1-\delta)]\, \tau^e \alpha^g R_t^e \left(\frac{A_t + N_t}{G_t} \right) + w_{t+1}^e \eta^e; \tag{41}$$

$$A_{t+1} = [r_{t+1} + q_{t+1}(1-\delta)]\, \tau^b \alpha^g R_t^b \left(\frac{A_t + N_t}{G_t} \right) + w_{t+1}^b \eta^b. \tag{42}$$

Equations (41) and (42) illustrate the interrelated evolution of bank and entrepreneurial net worth. Aggregate bank net worth A_t, through its effect on aggregate investment, affects not only the future net worth of banks, but the future net worth of entrepreneurs as well. Conversely, aggregate entrepreneurial net worth N_t has an impact on the future net worth of the banking sector.

Finally, recall that exiting banks and entrepreneurs consume the value of all available wealth. This implies the following for aggregate consumption of entrepreneurs and banks:

$$C_t^e = (1-\tau^e) q_t \alpha^g R_t^e I_t; \tag{43}$$

$$C_t^b = (1-\tau^b) q_t \alpha^g R_t^b I_t. \tag{44}$$

2.9 The competitive equilibrium

A competitive equilibrium for the economy consists of (i) decision rules for c_t^h, i_t^h, l_{it} and W_{it}, k_{t+1}^h, u_t, M_t^c, D_t, and M_{t+1} that solve the maximization problem of the household, (ii) decision rules for $\widetilde{p_{jt}}$ as well as input demands k_{jt}, h_{jt}, h_{jt}^e, h_{jt}^b that solve the profit maximization problem of firms producing intermediate goods in (9), (iii) decision rules for i_t, R_t^e, R_t^b, R_t^h, a_t and d_t that solve the maximization problem associated with the financial contract (10)-(16), (iv) saving and consumption decision rules for entrepreneurs and banks, and (v) the following market-clearing conditions:

$$K_t = K_t^h + K_t^e + K_t^b; \tag{45}$$

$$u_t K_t^h + K_t^e + K_t^b; = \int_0^1 k_{jt} \mathrm{d}j; \tag{46}$$

$$H_t = \int_0^1 h_{jt} \mathrm{d}j; \tag{47}$$

$$Y_t = C_t^h + C_t^e + C_t^b + (1+\mu) I_t; \tag{48}$$

$$K_{t+1} = (1-\delta) K_t + \alpha^g R I_t; \tag{49}$$

$$d_t = \frac{D_t}{P_t}; \tag{50}$$

$$\overline{M}_t = M_t. \tag{51}$$

Equation (45) defines the total capital stock as the sum of holdings by households, entrepreneurs and banks. Next, (46) states that total capital services (which depend on the utilization rate chosen by households for their capital stock) equals total demand from intermediate-good producers. Equation (47) requires that the total supply of the composite labour input produced according to (28) equals total demand by intermediate-good producers. The aggregate resource constraint is in (48) and the law of motion for aggregate capital in (49). Finally, (50) and (51) represent the market-clearing conditions for funds invested in banks and for currency held.

3 Calibration

The utility function of households is specified as

$$u(c_t^h - \gamma c_{t-1}^h, l_{i,t}, M_t^c/P_t) = log(c_t^h - \gamma c_{t-1}^h) + \psi log(1 - l_{it}^h) + \zeta log(M_t^c/P_t). \qquad (52)$$

The weight on leisure ψ is set to 4.0, which ensures that steady-state work effort by households is equal to 30% of available time. One model period corresponds to a quarter, so the discount factor β is set at 0.99. Following results in Christiano et al. (2005), the parameter governing habits, γ, is fixed at 0.65 and ζ is set in order for the steady state of the model to match the average ratio of $M1$ to $M2$.

The share of capital in the production function of intermediate-good producers, θ^k, is set to the standard value of 0.36. Recall that we want to reserve a small role in production for the hours worked by entrepreneurs and bankers. To this end, we set the share of the labour input θ^h to 0.6399 instead of $1-0.36 = 0.64$, then choose $\theta^e = \theta^b = 0.00005$, which allows entrepreneurs and bankers to always have non-zero net worth. The parameter governing the extent of fixed costs, Θ, is set so that in steady state, profits equal zero. The persistence of the technology shock, ρ_z, is 0.95, while its standard deviation, σ_z, is 0.0015, which ensures that the model's simulated output volatility equal that of observed aggregate data.

Price and wage-setting parameters are set following results in Christiano et al. (2005). Thus, the elasticity of substitution between intermediate goods (ξ_p) and the elasticity of substitution between labour types (ξ_w) are such that the steady-state markups are 20% in the goods market and 5% in the labour market. The probability of not reoptimizing for price setters (ϕ_p) is 0.60 while for wage setters (ϕ_w), it is 0.64.

The capital utilization decision is parameterized as follows. First we require that $u = 1$ and $\upsilon(1) = 0$ in the steady state, which makes the steady state independent of $\upsilon(.)$. Next, we set $\sigma_u \equiv \upsilon''(u)(u)/\upsilon'(u)$ to 0.01 for $u = 1$. This elasticity implies that, following a one-standard deviation monetary policy shock, capacity utilization's peak response is 0.4%, matching the empirical estimates reported in Christiano et al. (2005).

Monetary policy is calibrated using the estimates in Clarida et al. (2000), so $\rho_r = 0.8$, $\rho_\pi = 1.5$, and $\rho_y = 0.1$. The rate of inflation targeted by monetary authorities, $\overline{\pi}$, also the steady-state inflation rate, is 1.005, or 2% on a net, annualized basis. The standard deviation of the monetary policy shock σ^{mp} is set to 0.0016, which ensures that a one-standard-deviation shock displaces the interest rate by 0.6 percentage points, as in the empirical evidence (Christiano et al., 2005).

The parameters that remain to be calibrated (α^g, α^b, b, R, μ, τ^e, τ^b) are linked to capital production and the financial contract between entrepreneurs and banks. We set α^g to 0.9903, so that the (quarterly) failure rate of entrepreneurs is 0.97%, as in Carlstrom and Fuerst (1997). The remaining parameters are such that the model's steady state

Table 1: Baseline Parameter Calibration

Household Preferences and Wage Setting							
	γ	ζ	ψ	β	ξ_w	ϕ_w	
	0.65	0.027	4.0	0.99	21	0.6	
Final Good Production							
θ_k	θ_h	θ_e	θ_b	ρ_z	σ_z	ξ_p	ϕ_p
0.36	0.6399	0.00005	0.00005	0.95	0.0015	6	0.64
Capital Good Production and Financing							
	μ	α^g	α^b	R	b	τ_e	τ_b
	0.025	0.99	0.75	1.21	0.16	0.78	0.72
Resulting Steady-State Characteristics							
	κ	I/N	BOC	ROE	I/Y	K/Y	
	14%	2.0	5%	15%	0.198	11.8	

displays the following characteristics: 1) a 14% capital adequacy ratio (κ) which matches the 2002 average, risk-weighted capital-asset ratio of U.S. banks, according to BIS data; 2) a leverage ratio I/N (the size of entrepreneurial projects relative to their accumulated net worth) of 2.0; 3) a ratio of bank operating costs to bank assets (BOC) of 5%, which matches the estimate for developed economies in Erosa (2001); 4) a 15% annualized return on bank net worth (bank equity, ROE), matching the evidence reported by Berger (2003); 5) a ratio of aggregate investment to output of 0.2, and 6) an aggregate capital-output ratio of around 12%. Table 1 summarizes the numerical values of the model parameters. A solution to the model's dynamics is found by linearizing all relevant equations around the steady state using standard methods.

4 The Transmission of Shocks

This section analyzes the transmission of monetary policy and technology shocks. The responses of our model economy to these disturbances provide a good evaluation of its framework since the empirical literature has produced a wealth of evidence about how actual economies respond to these shocks. We show that bank net worth (bank capital) influences the model's dynamics and helps generate long-lived, hump-shaped responses following these shocks, which accord well with the evidence. Furthermore, this influence manifests itself in counter-cyclical patterns in the capital adequacy ratio of banks, which match those present in aggregate data. Taken together, the results reported in this section suggest that our model constitutes a useful tool for studying the interaction between bank net worth, economic shocks, and monetary policy.

4.1 Monetary policy

Figure 2 presents the economy's response to a one standard deviation shock to the monetary policy rule (32). This shock translates into a 0.6% increase in the interest rate r_t^d. This magnitude, as well as the speed with which the rate returns to its steady-state value, match the VAR-based estimates reported in Christiano et al. (2005).

In addition to more standard effects on investment demand, the rise in interest rates shifts the supply of investment goods in our model. To see this, recall expression (20), which, expressed with economy-wide variables, becomes

$$(1 + r_t^d) \frac{d_t}{I_t} = q_t \alpha^g \left(R - \frac{b}{\Delta\alpha} - \frac{\mu}{q_t \Delta\alpha} \right). \tag{53}$$

The right side of the expression states that the per-unit share of project return that can be reserved for depositors is governed by the severity of the double moral hazard problem (measured by b and μ): this share cannot increase when the required return on deposits r_t^d rises. This means that the increase in r_t^d exacerbates the moral hazard problem affecting the relationship between banks and households since it becomes more difficult to satisfy the participation constraint for deposits while keeping the contract incentive-compatible.

The left-hand side of the expression indicates that, as a result, the reliance on deposits for financing a given-size project, the ratio d_t/I_t, must fall. This means that banks and entrepreneurs must invest more of their own net worth in financing entrepreneurial projects. Figure 2 shows that this effect, arising from market discipline, is quantitatively significant: the ratio of bank capital to assets (i.e. the capital adequacy ratio κ_t) increases on impact by about 1% and, similarly, entrepreneurial leverage (I_t/N_t) decreases by 0.5%.

Because they consist of retained earnings from previous periods, aggregate levels of bank and entrepreneurial net worth (A_t and N_t, respectively) do not react significantly to the shock's impact. The adjustments in leverage are therefore driven by sizeable reductions in bank lending and aggregate investment. Figure 2 shows that this effect is important, as aggregate investment I_t falls by 0.8% in the impact period.

The drop in aggregate investment depresses earnings for banks and entrepreneurs, leading to lower levels of net worth. This sets the stage for second-round effects on investment in subsequent periods, as the lower levels of net worth further reduce the ability of banks to attract loanable funds. As a result, aggregate investment continues to fall, bottoming out in the fourth period following the shock, at a level 1.5% below steady state. Bank and entrepreneur net worth also experience persistent declines, reaching low points (declines of about 1.5%) five periods after the shock. Note that this pronounced hump-shaped pattern in aggregate investment is not the product of capital adjustment costs, as in Christiano et al. (2005); instead it results from the interplay between aggregate investment, on the one hand, and bank and entrepreneurial net worth, on the other.

The monetary tightening also generates more standard effects on the economy. The increase in the nominal rate discourages consumption and output, but price and wage rigidities limit the range of possible price declines. As a result, inflation declines very slightly, bottoming out five periods after the shock at a rate only 0.2% below its steady-state value. This subdued response in prices translates into a stronger response in output, which continues to decline after the onset of the shock, reaching a low point in the fourth period, at -0.45% below steady-state.

Overall, Figure 2 shows that the various propagation mechanisms present in the model, in which the dynamics of bank net worth figure prominently, generate economic responses that last well beyond the immediate effects of the monetary tightening on interest rates themselves. This timing gap between the interest rate effects of the shock and its ultimate impact on variables like output and inflation matches well with the empirical evidence on these shocks (Christiano et al., 2005).

4.2 Technology

Next, Figure 3 reports the effects of a one-standard deviation negative technology shock. This shock decreases productive capacities in the final-good sector and is expected to persist for several periods. The expectation that productivity will be low over a prolonged interval reduces future rental income from capital, so that desired investment purchases by households decline, as does the price of capital q_t.

The technology shock also has supply-side effects on the market for capital. Note from (53) that a decrease in q_t acts in a manner equivalent to the increase in r_t^d examined above: it exacerbates moral hazard, by reducing the value of project return that is reserved for bank investors. To keep the contract incentive-compatible, banks and entrepreneurs must invest more of their own net worth in financing projects, that is they must reduce their leverage. The capital adequacy ratio κ_t thus increases on impact and reaches a peak six periods after the onset of the shock, at a level 1.3% above steady state. Similarly, entrepreneurial leverage I_t/N_t exhibits a persistent decline, reaching a trough 6 periods after the onset of the shock, at a level 0.5% below steady state.

As was the case after a monetary tightening, the initial adjustment is largely borne by aggregate investment I_t, which declines significantly. Declines in aggregate investment depress earnings and thus lead to lower levels of bank and entrepreneurial net worth in future periods. Lower levels of net worth then help propagate the effects of the shock into future periods. Figure 3 shows that this shock has very persistent effects, with investment declining for an extensive period of time and bottoming out 16 periods after the shock, almost 8 percentage points below steady state.

An adverse technology shock also puts upward pressures on inflation. The policy rule (32) shows that short term rates increase in response to limit these pressures. Monetary authorities thus follow a tight policy after the onset of the shock, increasing rates by as much as 80 basis points. Such a policy stance represents an additional source of weakness in the economy but limits the rise in inflation to 60 basis points (on an annualized basis).

Finally, the shock represents a decrease in wealth for households, which leads to consumption decreases. In our environment with nominal price and wage rigidities, these lead to persistent decreases in output, which bottoms out close to 2% below steady state 15 periods after the onset of the shock.

4.3 Cyclical Properties of Capital Adequacy Ratios

In Figures 2 and 3, capital adequacy ratios are high when economic activity weakens and decrease when activity recovers. Since there are no regulatory capital requirements in our model, these counter-cyclical movements are market-generated, a product of the discipline imposed on banks in response to moral hazard.

To test the validity of this mechanism, Table 2 compares these with those from actual capital-asset ratios of the U.S. banking system. If their behavior is comparable, it provides evidence in favour of our model and suggests that market discipline affects banks' decisions on lending and capitalization.

First, we document the facts. Panel A of Table 2 shows that bank capital-asset ratios in the United States are one-third as volatile as output, while investment and bank lending are over four times as volatile.[15] Furthermore, capital-asset ratios are persistent, with one-step and two-step autocorrelations of 0.9 and 0.8, respectively. Next, capital-asset ratios are countercyclical with respect to output, but also with respect to investment and bank lending. Moreover, these negative correlations extend to various leads and lags. In short, capital-asset ratios are not very volatile, are persistent, and are negatively related to economic activity. Importantly, the counter-cyclical pattern depicted in Table 2 is also present in Canadian data (Illing and Paulin, 2004) and using alternative data sources (Adrian and Shin, 2008).

[15] The bank capital-asset ratio is the sum of *tier1* and *tier2* capital, over risk-weighted assets. *tier1* capital is the sum of equity capital and published reserves from post-tax retained earnings; *tier 2* capital is the sum of undisclosed reserves, asset revaluation reserves, general provisions, hybrid debt/equity capital instruments, and subordinated debt. The risk weights follow the Basel I classifications and are: 0% on cash and other liquid instruments, 50% on loans fully secured by mortgage on residential properties, and 100% on claims to the private sector.

Table 2. Cyclical Properties of the Capital-Asset Ratio

Variable	$\frac{\sigma(X)}{\sigma(GDP)}$	*Correlation of Capital-Asset Ratio with:* X_{t-2}	X_{t-1}	X_t	X_{t+1}	X_{t+2}
Panel A: US Economy (1990:1-2005:1)						
Banks' Capital-Asset Ratio	0.34	0.79	0.90	1.00	0.90	0.79
Investment	4.26	−0.45	−0.42	−0.36	−0.25	−0.17
GDP	1.00	−0.36	−0.31	−0.23	−0.12	−0.07
Bank Lending	4.52	−0.52	−0.62	−0.70	−0.69	−0.67
Panel B: Model Economy						
Banks' Capital-Asset Ratio (κ_t)	1.49	0.61	0.85	1.00	0.85	0.61
Investment	3.63	0.31	0.06	−0.22	−0.44	−0.59
GDP	1.00	0.11	−0.17	−0.46	−0.65	−0.73
Bank Lending	3.75	0.20	−0.07	−0.36	−0.53	−0.64

Note Capital-Asset Ratio: *tier1* + *tier2* capital over risk weighted assets (source BIS); Investment: Fixed Investment, Non Residential, in billions of chained 1996 Dollars (source BEA); GDP: Gross Domestic Product, in billions of chained 1996 Dollars (source BEA); Bank Lending: Commercial and Industrial Loans Excluding Loans Sold (source BIS). GDP, investment, and bank lending are expressed as the log of real, per-capita quantity. All series are detrended using the HP filter. For the model economy, results are averages, over 500 repetitions, of simulating the model for 100 quarters, filtering the simulated data, and computing the appropriate moments.

Panel B presents the results of repeated simulations of our model economy: it shows a broad concordance between the model's predictions for κ_t and the observed behavior of the capital-asset ratios of banks. Notably, the model replicates well the high serial correlation of this ratio and its counter-cyclical movements with respect to output, investment, and bank lending. However, the model generates too much volatility κ_t, relative to observed data, perhaps as a result of our framework's sole reliance on market discipline to motivate solvency constaints on banks. Overall, the general concordance between model and data constitutes an important test of the validity of our framework. Further, it suggests that market discipline may have played an important, though not exclusive, role in shaping the evolution of bank capital and their capital-asset ratios over the recent monetary history.[16]

[16] This finding provides some support to dispositions of the updated Basle accord on capital requirements calling for market discipline to constitute one of the three 'pillars' of bank capital regulation.

5 Bank Capital and Shocks

The previous section showed that the propagation mechanism centered on bank capital and entrepreneurial net worth helps generate responses to shocks in line with the evidence. Further, it reported that one key feature of this mechanism, the counter-cyclical movement in bank capital adequacy ratios, is also present in the data. Given this success, we use our framework to study the economic consequences of variations in bank capitalization. Specifically, we report the results of two experiments:

1. A comparison between the effects of negative shocks in economies where banks remain well-capitalized, and the effects of the same shocks in economies where bank capitalization weakens alongside economic activity.
2. The introduction of 'financial distress' shocks, which cause exogenous declines in bank capitalization.

5.1 Bank capital and the transmission of shocks

This subsection revisits the effects of technology and monetary policy shocks analyzed in section 4, allowing for differences in bank capitalization.

Technology shocks

Figure 4 depicts the effects of a one-standard-deviation negative technology shock in two economies. The full lines describe the responses of the baseline economy. The dashed lines illustrate an economy where bank net worth, instead of decreasing endogenously following the shock, is maintained at its steady-state level. This experiment allows us to verify if a better capitalized banking sector (where net worth remains relatively high during recessionary episodes) can have stabilizing effects and help absorbing adverse shocks.

Figure 4 reveals that it can. It shows that the economic downturn is both less pronounced and less persistent when banks remain well capitalized (dashed lines). Aggregate investment now bottoms out at a level (-3.7% below steady state) less than half of the decline (-7.8% below steady state) observed in the baseline economy. Important differences in the response of output are also present: it now bottoms out at only -1.24% below steady state, while the baseline economy reaches a trough as low as -1.9%. Moreover, investment and output bottom out earlier in the better-capitalized economy (11 and 10 periods after the shock, respectively) than in the baseline case (where the trough was attained after 16 quarters for investment and 14 periods for output).

These differences arise because in the alternative economy where banks remain well-capitalized, their capacity to attract loanable funds and finance firms is undiminished; as a result, entrepreneurial leverage recovers rapidly, even overshooting its steady-state level 4 periods after the onset of the shock. The relative abundance of bank capital is also reflected in the response of the market determined capital adequacy ratio (κ_t), which is significantly higher than baseline throughout the episode.

These differences have implications for the conduct of monetary policy. As discussed in Section 4, the baseline economy faces sizeable inflationary pressures following the negative technology shock. These pressures compel monetary authorities to tighten policy and increase short term rates, by as much as 80 basis points. In the alternative economy, the relatively abundance of bank capital limits the reductions in bank lending, aggregate investment and economic activity. This also reduces the inflationary pressures, so that the monetary authority can set policy more moderately. Short term rates only increase by 50 basis points, and the increase in inflation is 50 basis points less than in the baseline case.

A banking sector that remains well-capitalized can thus reduce the length and amplitude of recessionary episodes following adverse technology shocks. It can also dampen the inflationary pressures resulting from these shocks, which reduces the tightening monetary authorities must apply to keep inflation on target.

Monetary policy shocks

Figure 5 compares the effects of a monetary policy tightening in two different economies. Again, solid lines show the responses of the baseline economy while dashed lines describe the alternative economy where bank remain well-capitalized throughout the episode.

Although less striking than for technology shocks, the ability of well-capitalized banks to mitigate the shock's impacts remains. Aggregate investment bottoms out about 1.3% below steady-state in the alternative economy, compared to 1.5% in the baseline case, and reaches this trough after 6 periods rather than 9. The differences in output's peak responses between the two economies are small but the better-capitalized economy exhibits this response slightly earlier, after 5 periods, rather than 6 in the baseline case. The more modest declines in aggregate investment are reflected in the responses of entrepreneurial net worth, which itself exhibits a less persistent response with a more modest peak.

Figure 5 shows that the declines in inflation are very similar in the two economies, even though the investment and output responses caused by the shock are less pronounced in the alternative economy with abundant bank capital. This result suggests that in such an economy, a disinflationary monetary tightening could be less costly, that is, the 'sacrifice ratio' (the loss in output necessary to achieve a given decrease in inflation) might be smaller in economies with well-capitalized banks. This would be because banks in the alternative economy do not lose their ability to attract loanable funds and lend, so that a tightening orchestrated by an interest rate shock has less effects on investment and output.

5.2 A credit crunch: shock to the banking sector

The previous subsection analyzes how the banking sector, through the dynamics of bank capital, affects the transmission of shocks. In recent years, however, episodes of increased volatility in financial markets have led researchers to ask whether shocks that originate within financial markets have important effects on the larger economy, and how policy makers should react to them.

In this context, this subsection considers the effects of a shock that arises in the banking sector of our model and leads to exogenous declines in bank net worth. Following the theoretical contribution of Holmstrom and Tirole (1997), this shock might be interpreted as a 'credit crunch', caused perhaps by sudden deteriorations in the balance sheets of banks, as loan losses and asset writedowns reduce bank equity and net worth. Recent upheavals in financial markets worldwide, characterized by growing loan loss provisions, large asset writedowns and dramatic reductions in profits of financial institutions, appear to reflect disturbances of this kind.[17]

We capture the effects of such episodes by assuming that the real assets of the banking sector may be subject to episodes of accelerated depreciation. In this context, aggregate bank net worth, first defined in (38), becomes

$$A_t = \left[r_t + q_t(1-\delta x_t)\right] K_t^b + \eta^b w_t^b, \tag{54}$$

where x_t represents the occurrence of financial distress and follows

$$\log x_t = \rho_x \log x_{t-1} + \varepsilon_{xt},\ \varepsilon_{xt} \sim (0, \sigma_x). \tag{55}$$

As (54) shows, a positive shock to x_t unexpectedly decreases the value of bank assets and thus aggregate bank capital.

Figure 6 depicts the effects of such a shock, whose size has been set to place the initial decrease in bank capital at 5%. This magnitude appears in line with recent evidence on the likely effects of financial distress episodes.[18] The decreased capitalization reduces the banking sector's capacity to arrange financing for entrepreneurs and, as a result, entrepreneurial leverage decreases by about 0.5%. In addition, the sudden scarcity of bank capital implies that the financial contracts is set to economize on it. This explains the drop in the capital adequacy ratio: κ_t falls by 4 percentage points. Finally, the reduced financing available to entrepreneurs translates into lower aggregate investment, which falls by 0.5% on impact.

[17] The exact source of this sudden deterioration in the balance sheets of banks, which we leave unspecified, could arise from severe weakness in a specific sector or foreign market where banks have important activities.

[18] We follow Goodfriend and McCallum (2007) and set ρ_x to 0.9. They argue that such a number adequately "reflects modest persistence associated with resolving financial distress." Christiano et al. (2007) also assume that shocks originating within financial markets have moderate to high serial correlation.

As discussed above, decreases in aggregate investment depress earnings in the banking and entrepreneurial sectors, which sets the stage for decreases in bank earnings, lower bank net worth (capital), and thus second-round effects in subsequent periods. As a result, aggregate investment decreases for several periods and bottoms out 2.2% below its steady-state value, 11 periods after the onset of the shock. Output's peak response is a decline of 0.4% relative to steady state, again occurring 11 periods after the initial shock. The banking sector shock also creates some mild inflationary pressures, which require monetary authorities to increase short term rates slightly.

Overall, the episode of financial distress captured by the shock leads to a recessionary period, with output and investment falling significantly for several periods. The shock also creates some inflationary pressures, which must be confronted with higher short term rates. Consistent with the message of this section, therefore, a sudden scarcity of banking net worth depresses economic activity and affects the conduct of monetary policy.

Importantly, the market-determined bank capital adequacy ratios are procyclical following the shock, decreasing at the same time economic activity weakens. This suggests that banking norms should be loosened during recessions, if the origin of the economy's weakness originates from financial sector fragility. Put differently, this result introduces an important nuance to debates over cyclicality in bank solvency ratios: during times of weakening economic activity, the source of weakness in the economy might determine whether banking norms should be loosened or tightened.

6 Conclusion

This paper presents a quantitative business cycle model that emphasizes the role of bank capital in the transmission of shocks. Bank capital is important in the model because its presence mitigates moral hazard between banks and suppliers of loanable funds and, in doing so, facilitates bank lending. The model shows that, following adverse shocks, economies with well-capitalized banking sectors experience smaller decreases in bank lending and less pronounced downturns. Bank capital thus increases an economy's ability to absorb shocks and, in doing so, potentially affects the conduct of monetary policy. One key aspect of the framework is that it generates market-determined movements in bank capital adequacy ratios. In simulations based on our benchmark calibration, these ratios covary negatively with the cycle, a fact that broadly matches observed movements in actual economies. However, we also show that, following adverse shocks to financial markets, capital adequacy ratios are procylical, as banking norms loosen with economic activity. Our findings thus suggest that the nature of the shocks affecting an economy determine the cylicality of capital adequacy ratios.

This paper represents one step in establishing a framework to study the links between the balance sheet of banks and economic fluctuations. One first direction for future research would refine the structure of bank monitoring, to reflect the interaction between the business cycle and the monitoring intensity firms receiving external financing are subjected to.

A second important model extension would recognize that movements in capital-asset ratios reflect both the influence of regulatory requirements and of market discipline. Adding explicit regulatory requirements into our framework would enrich the analysis, and possibly lower the volatility in capital-to-asset ratios (the prospect of hitting a regulatory floor inciting banks to reduce their capitalization's volatility).

Finally, future research could allow the model to take into account the heterogeneity (in size or capitalization) that characterizes banking sectors in some countries. Tractability required that the present model abstract from such heterogeneity but important further insights and policy implications could potentially be gained from such work.

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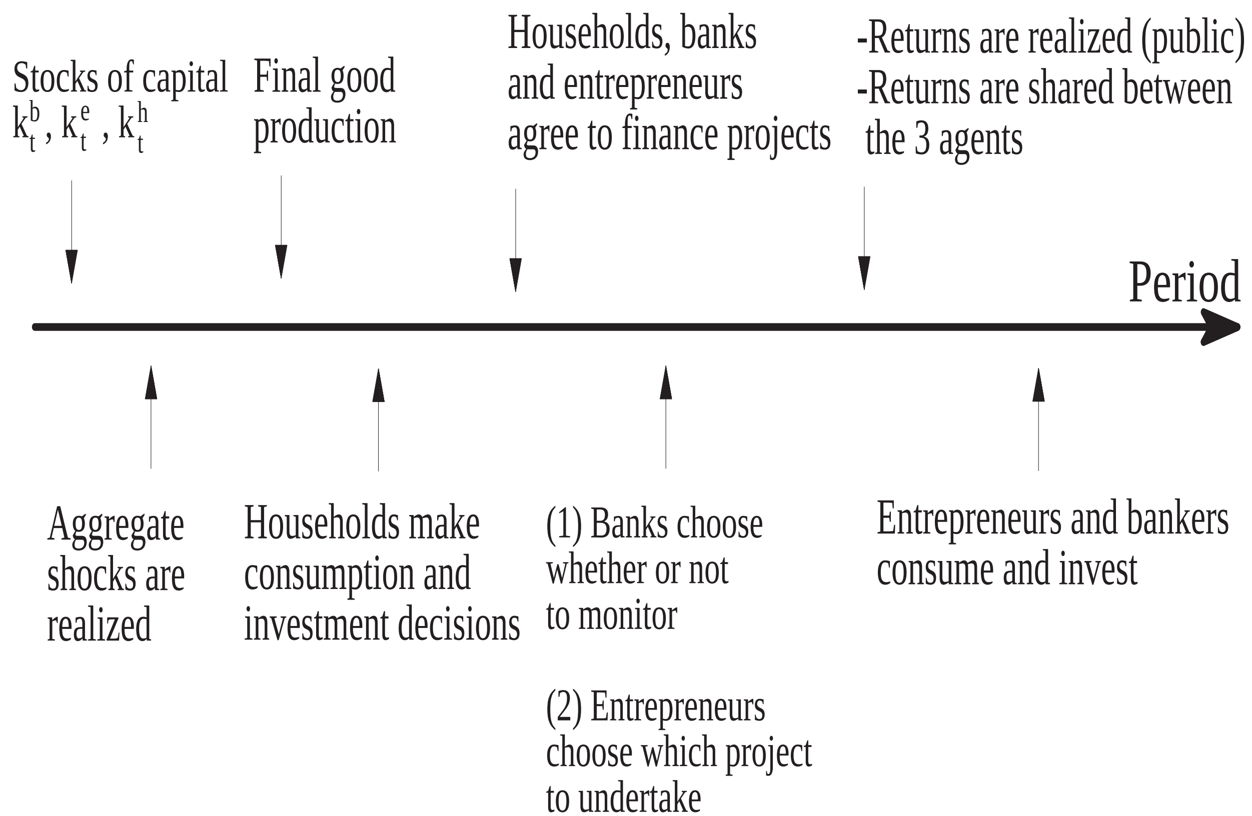

Figure 1. Timing of Events

Figure 2. One Standard Deviation Monetary Policy Tightening

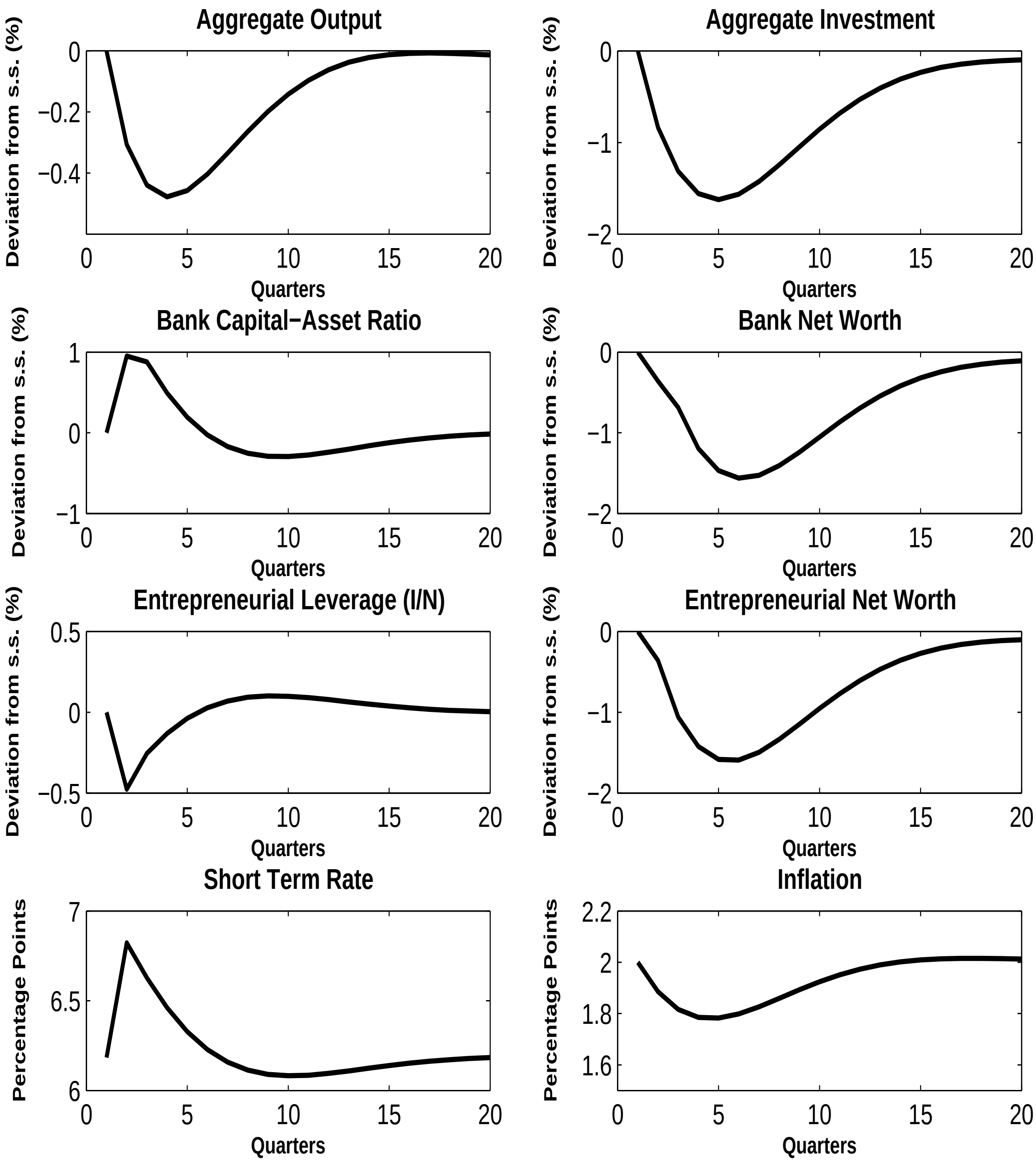

Figure 3. One Standard Deviation Adverse Technology Shock

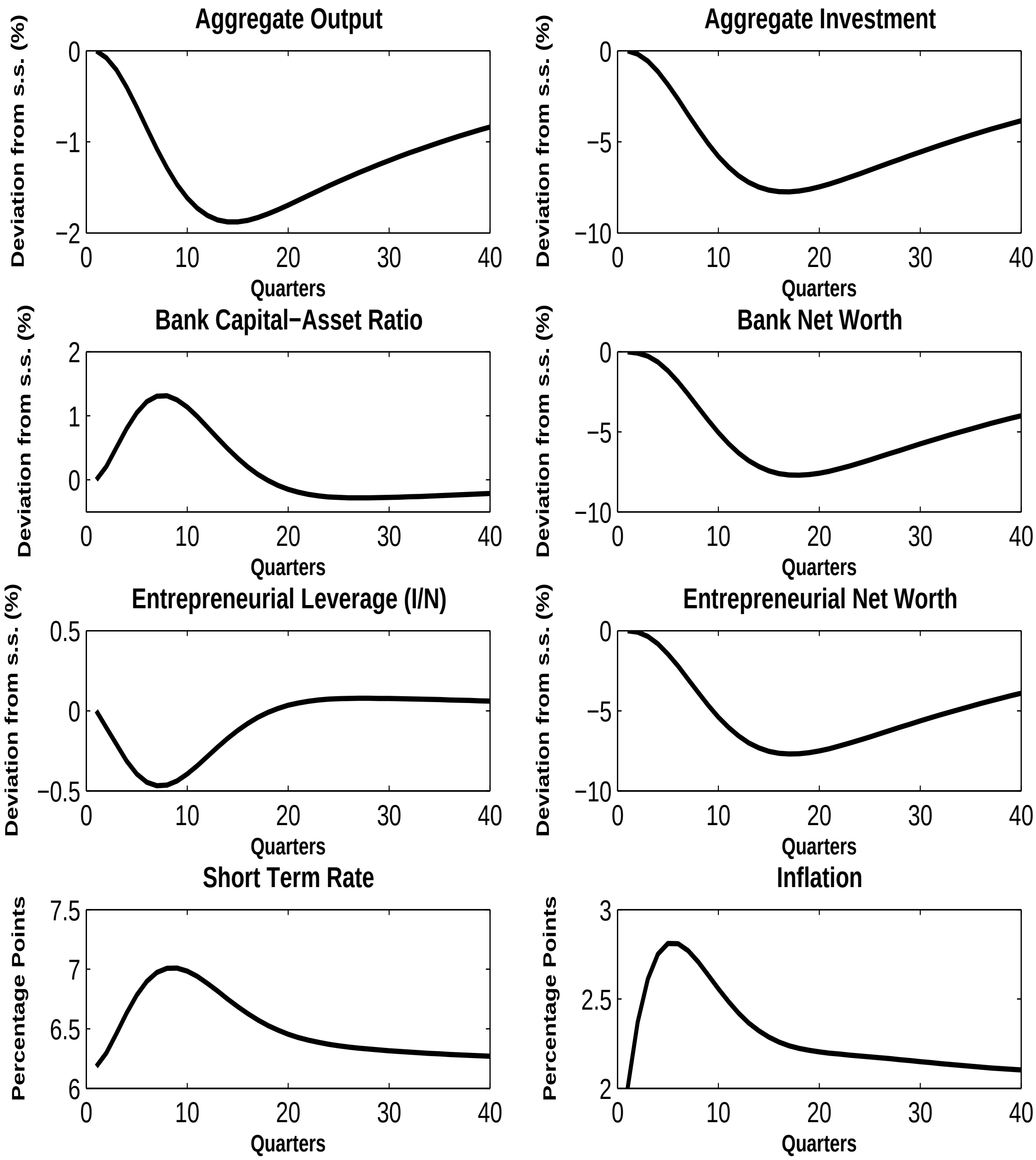

Figure 4. Banking Net Worth in the Transmission of a Negative Technology Shock

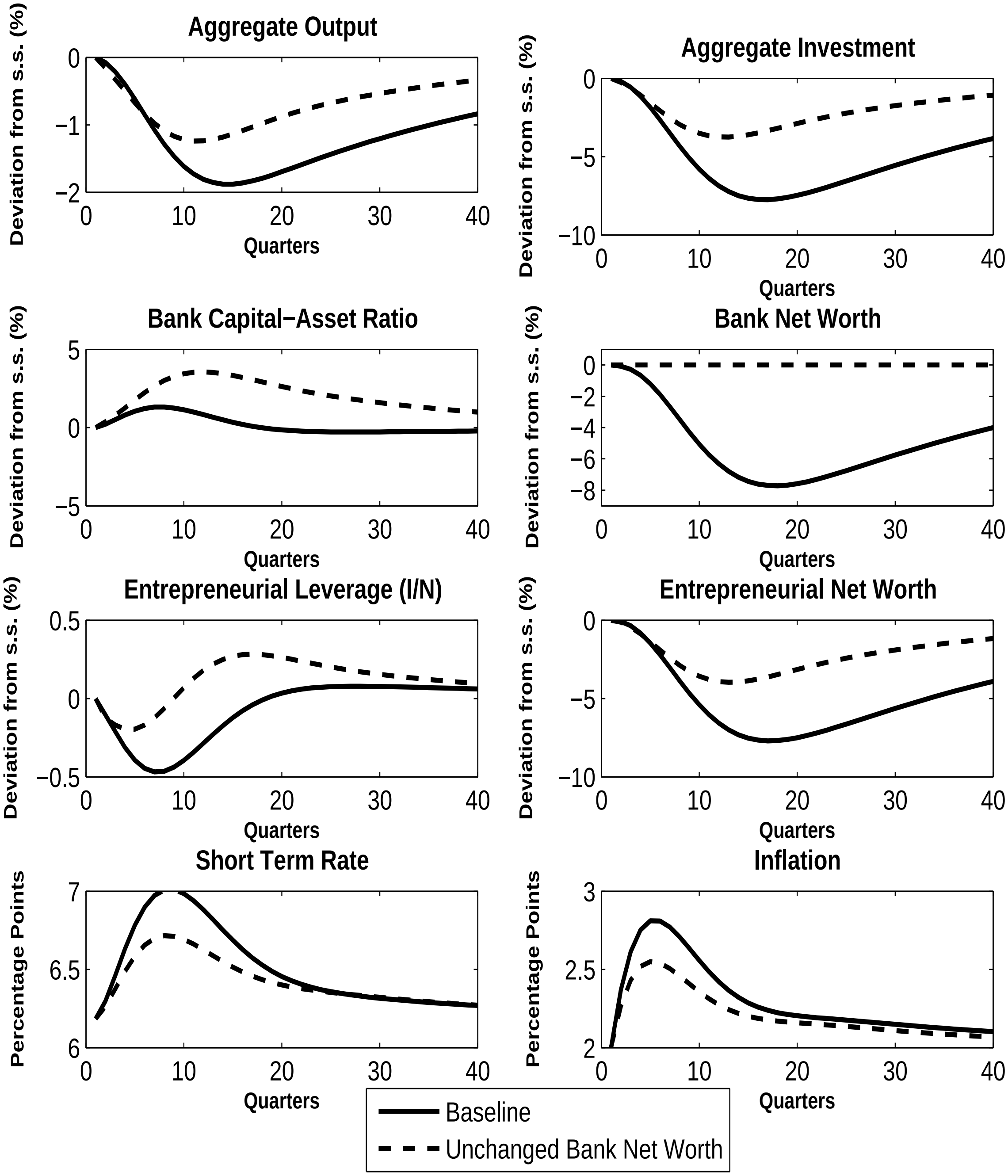

Figure 5. Banking Net Worth in the Transmission of a Monetary Tightening

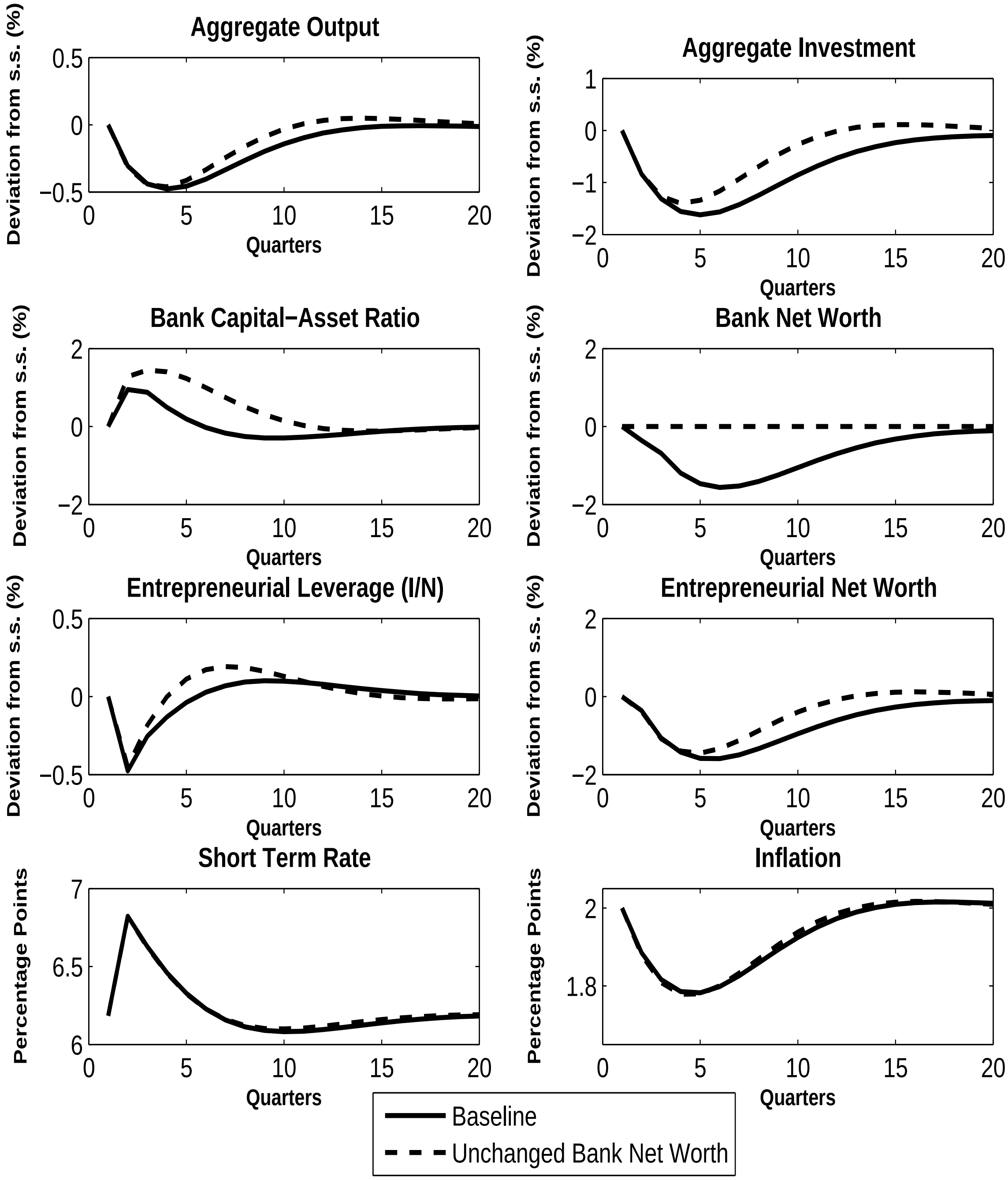

Figure 6. Banking Sector Shock